Design of a Tandem Racing Bicycle

MARK TAYLOR/STUFF

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Acknowledgements:

Damian Wiseman, Paralympics New Zealand

Motivation: Tokyo 2020 Paralympic Games (August 2021)

Hannah van Kampen (sighted pilot) & Emma Foy

- 3000m women's tandem individual pursuit
- 2019 & 2020 world champions & world record holders: 3:20.819

Motivation: Rio 2016 Tandem

Motivation: Rio 2016 Tandem

Frame design collaboration: Project contributions

ZENYTH PROJECTS LIMITED

- Geometric design
- Manufacture

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

- Finite element analysis
- Laminate optimisation
- Numerical race simulation

PARALYMPICS NEW ZEALAND

- Athlete data
- Funding

Method: Load case – starting effort

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Method: Load case – starting effort

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Method: Load case – starting effort

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Method: Load case – starting effort

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MARK TAYLOR / STUFF

Method: Load case – starting effort

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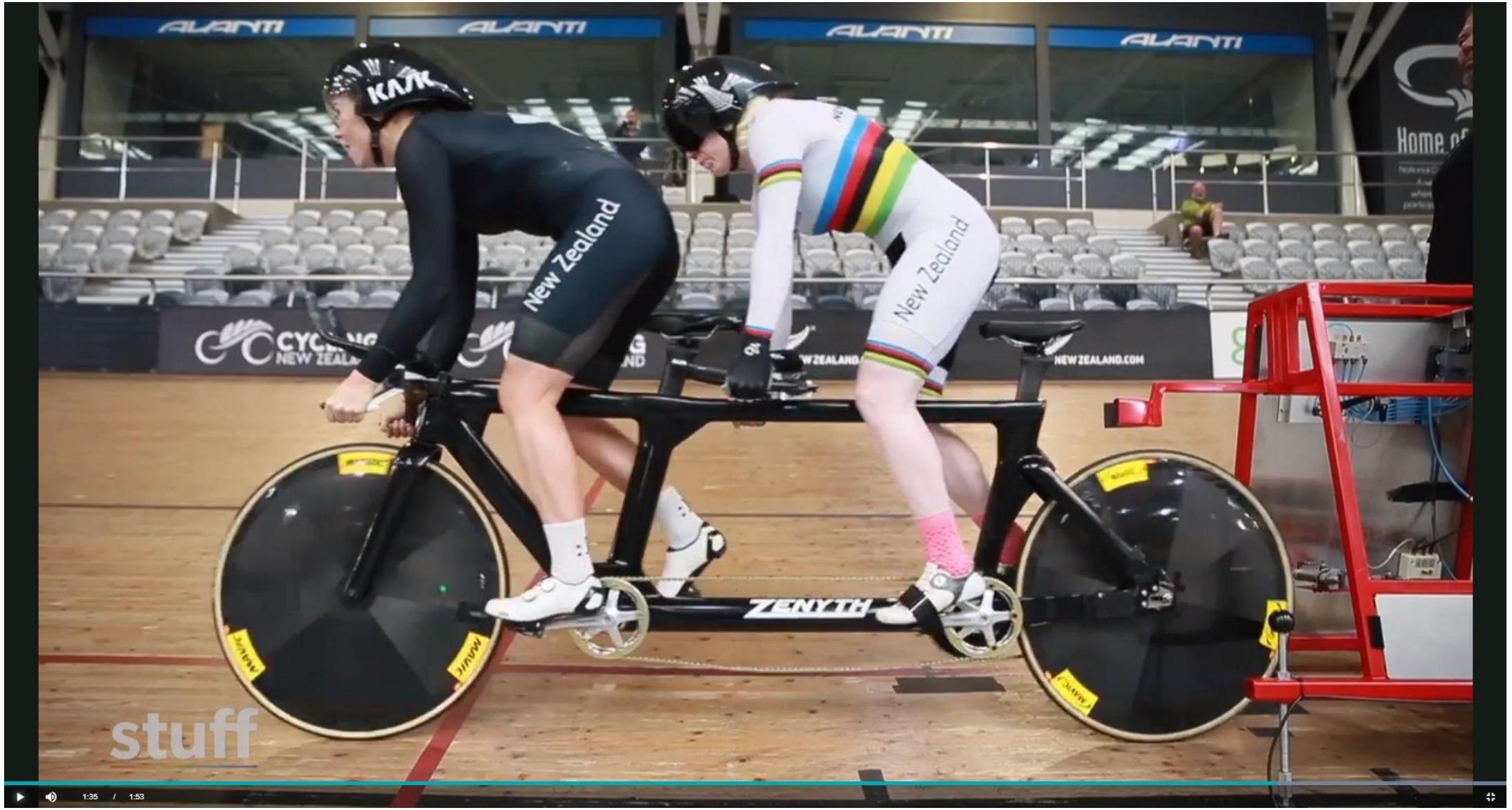
Method: Load case – starting effort



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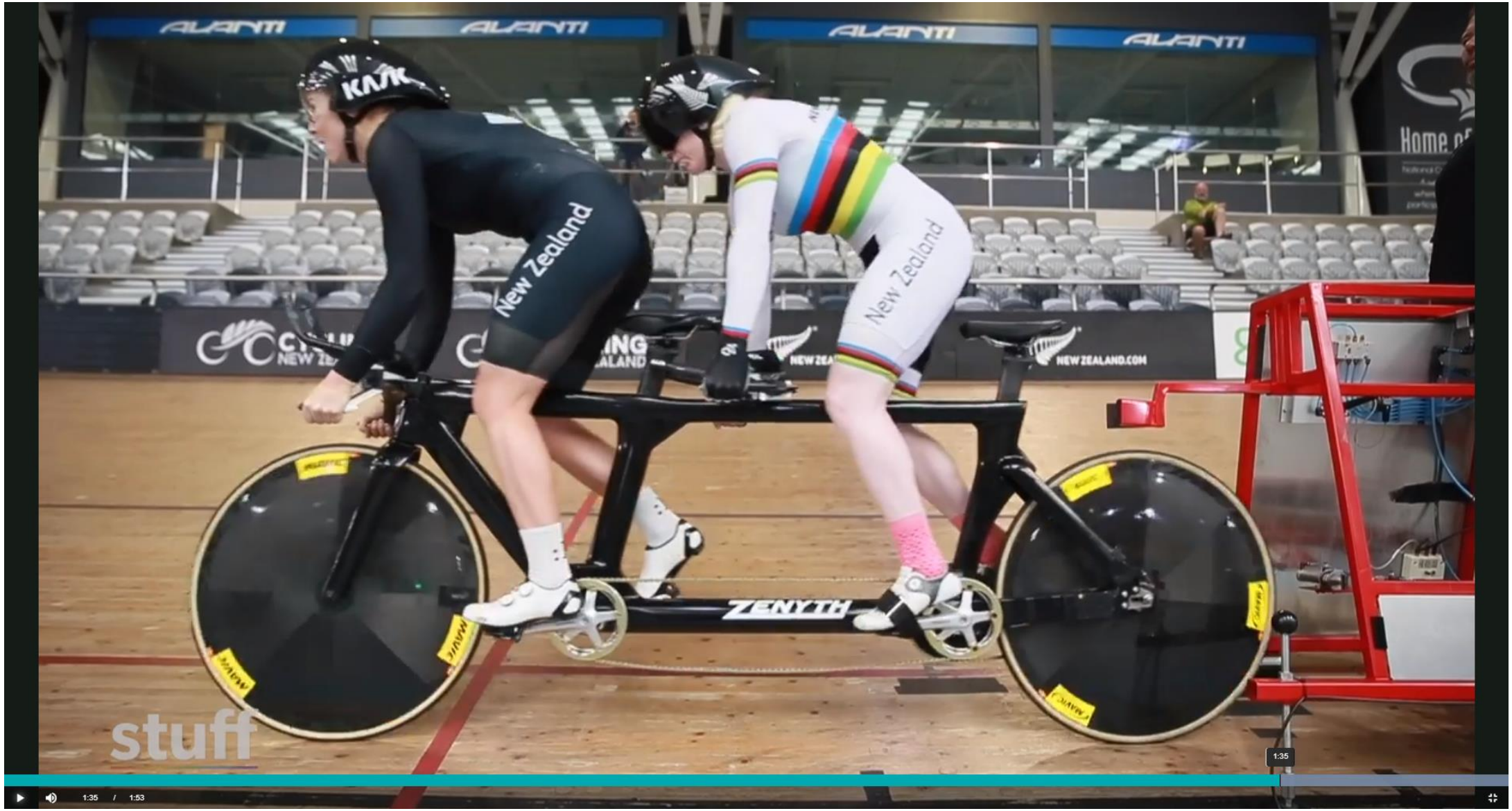
Method: Load case – starting effort



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Method: Load case – starting effort

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MARK TAYLOR / STUFF

Method: Load case – starting effort

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MARK TAYLOR / STUFF

Method: Load case – starting effort

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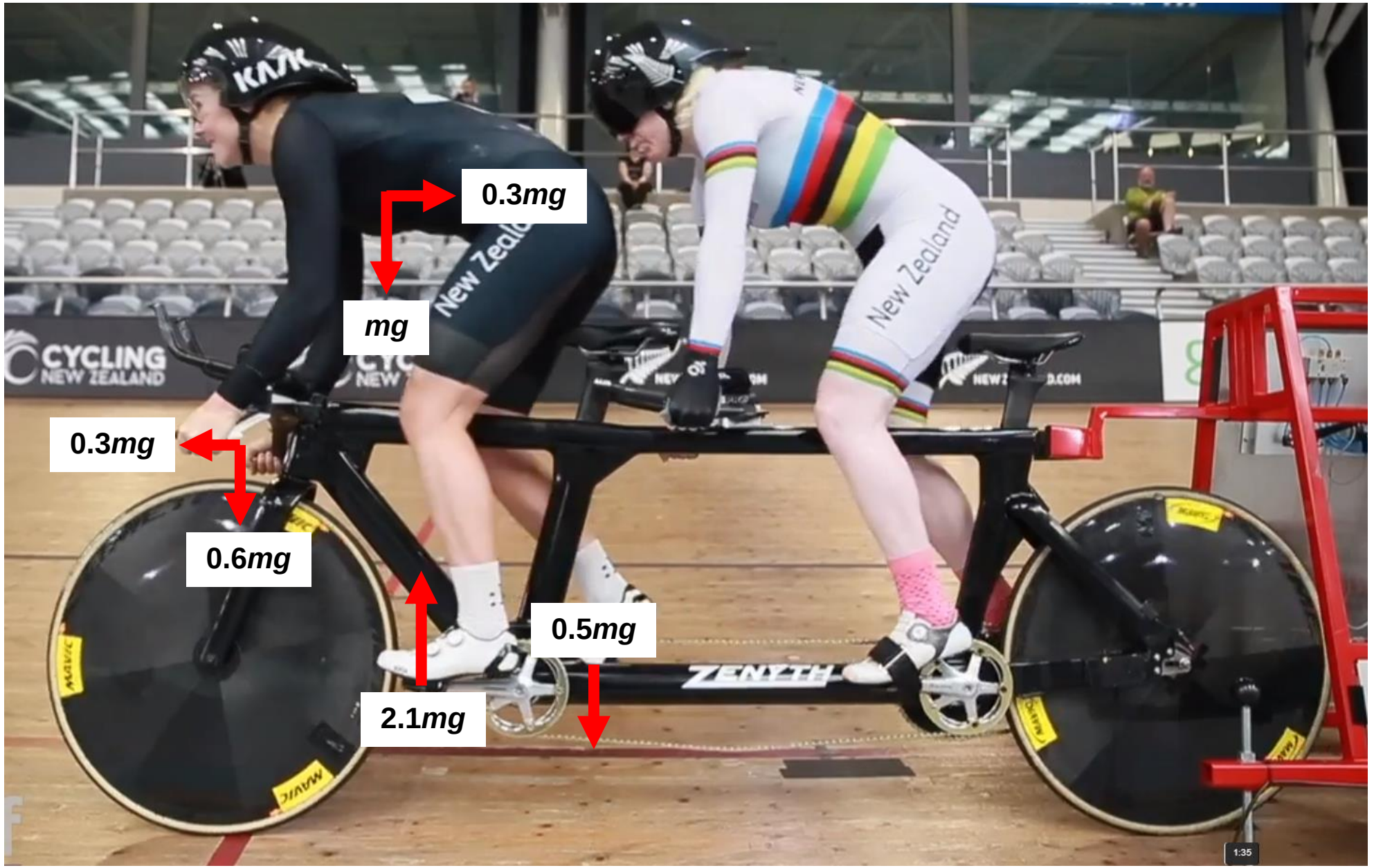
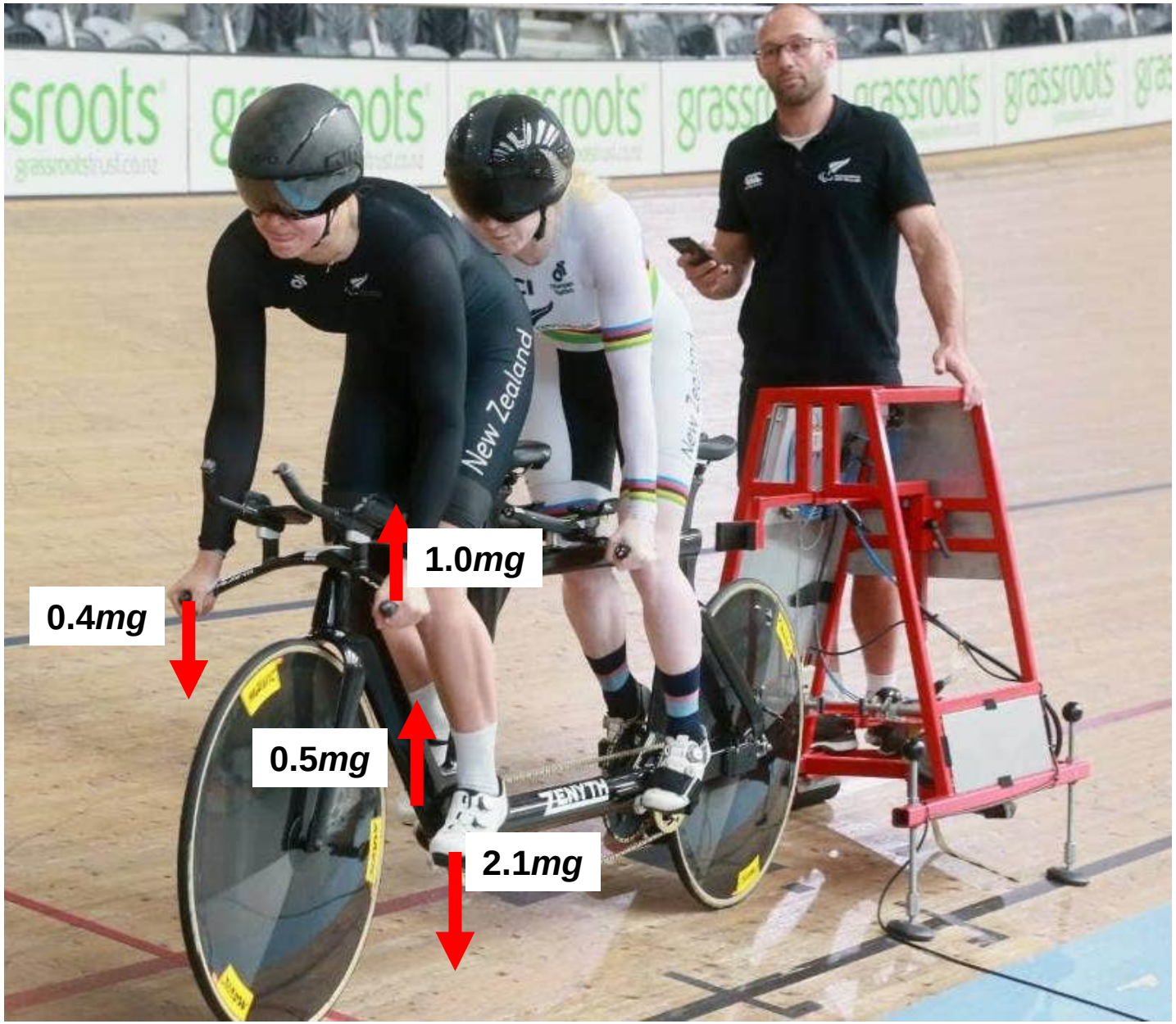
MARK TAYLOR / STUFF

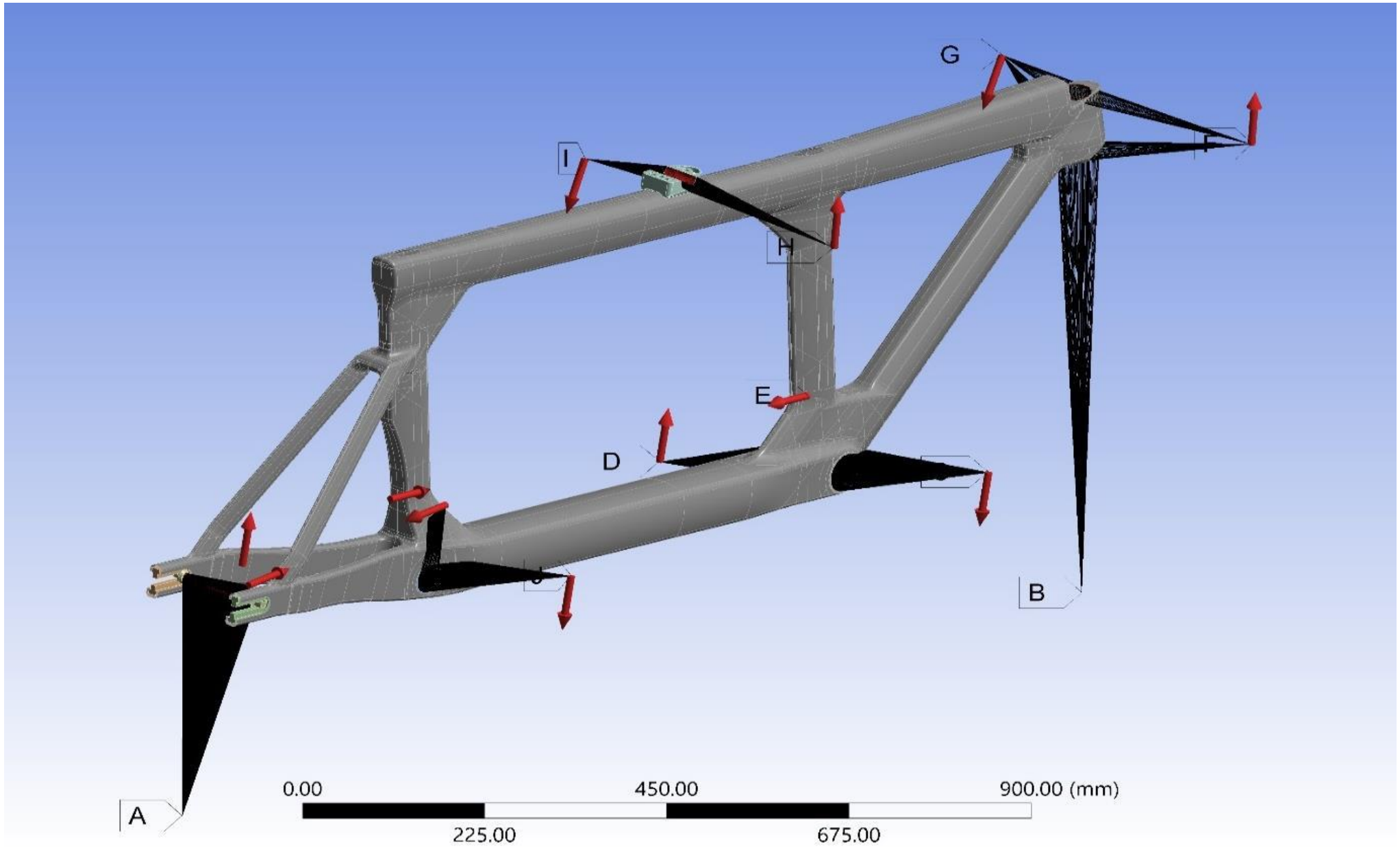
Method: Equilibrium of cyclist



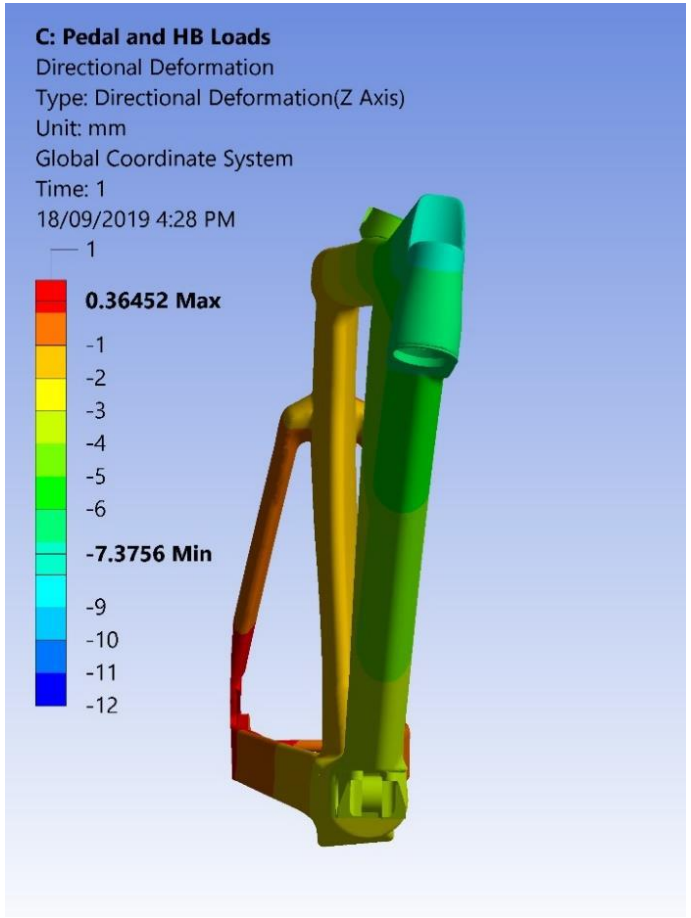
Method: Vertical forces applied to bicycle

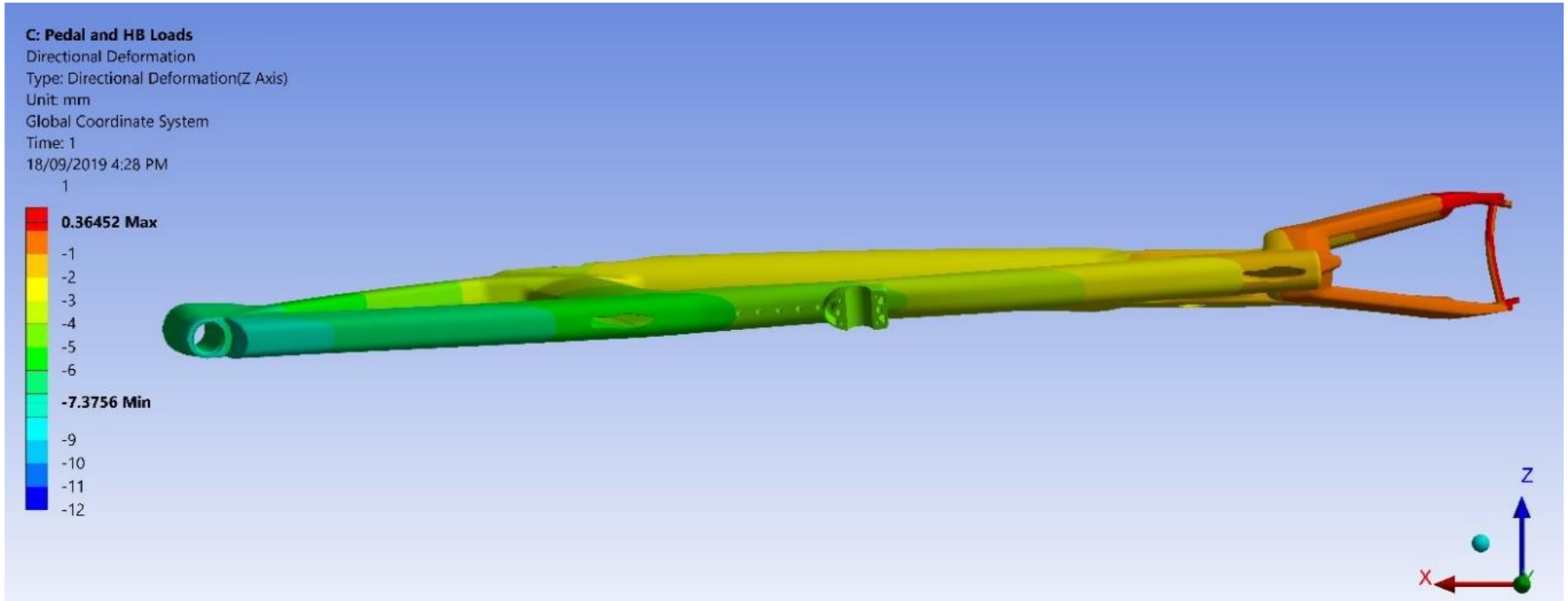


Method: Finite element analysis

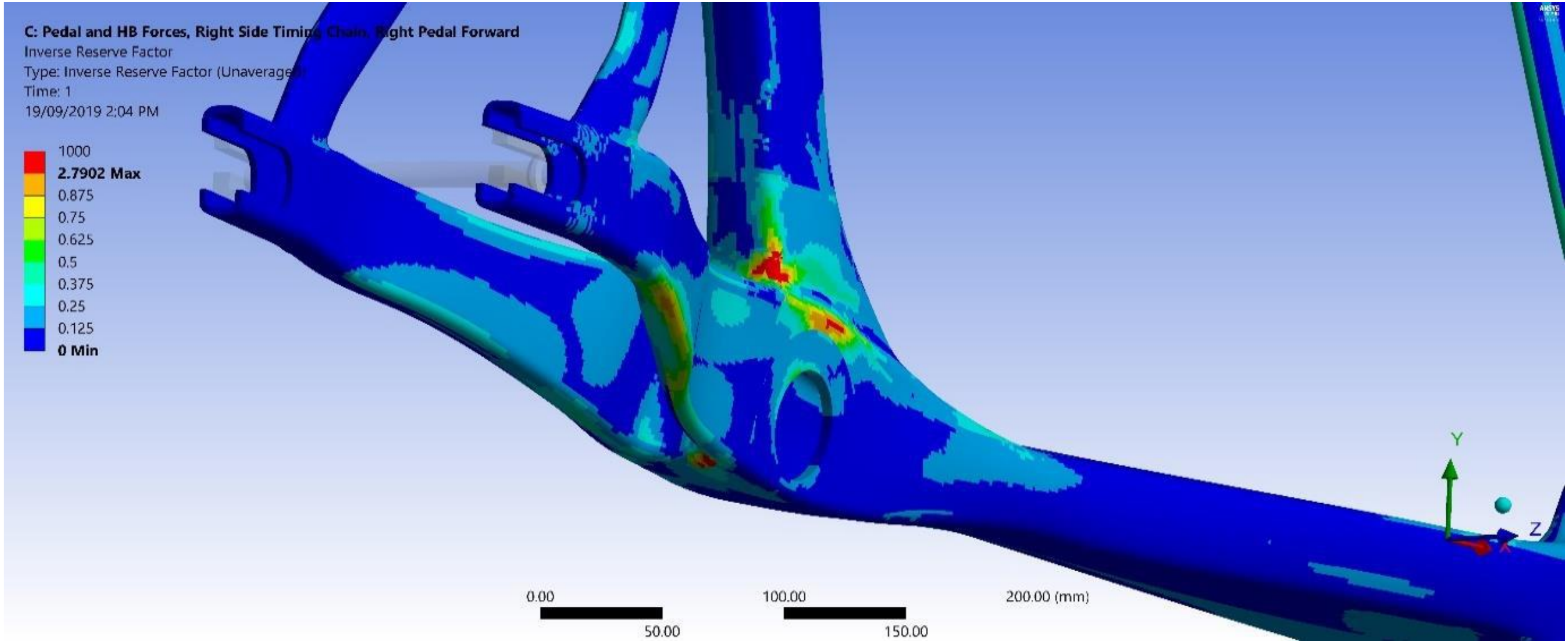


Results: Deflection



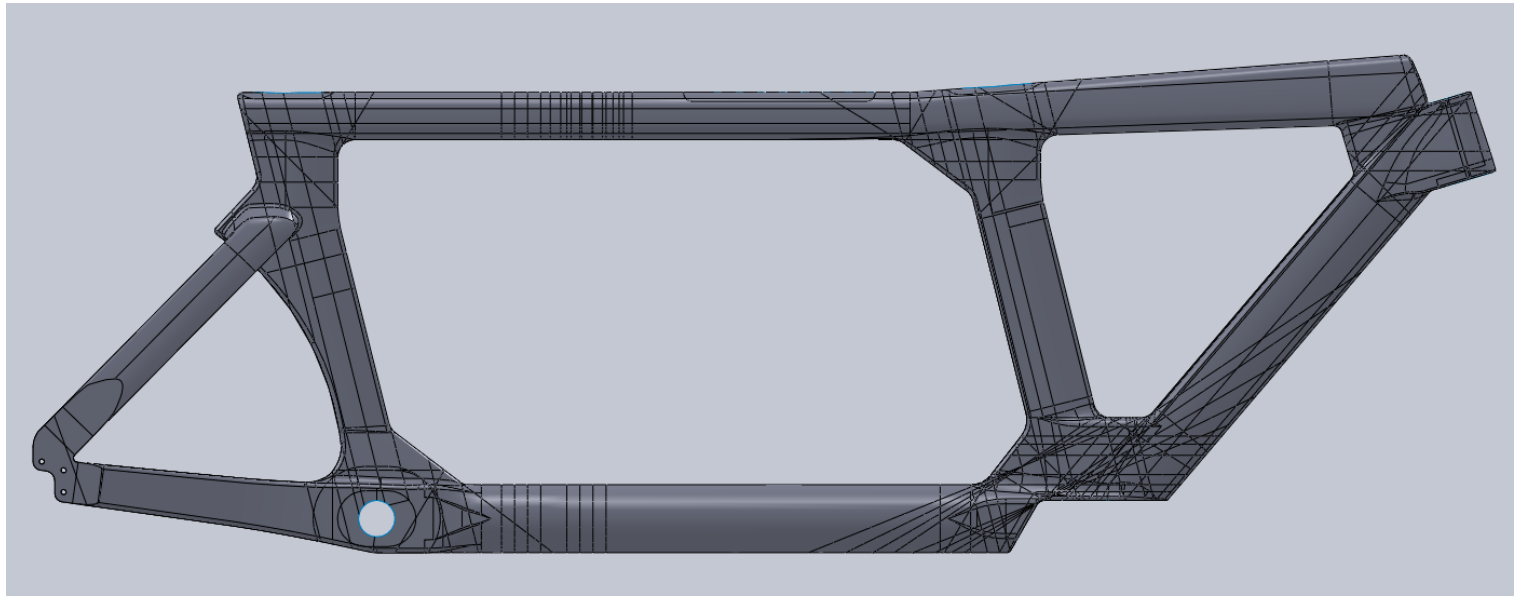


Results: Ply failure prediction

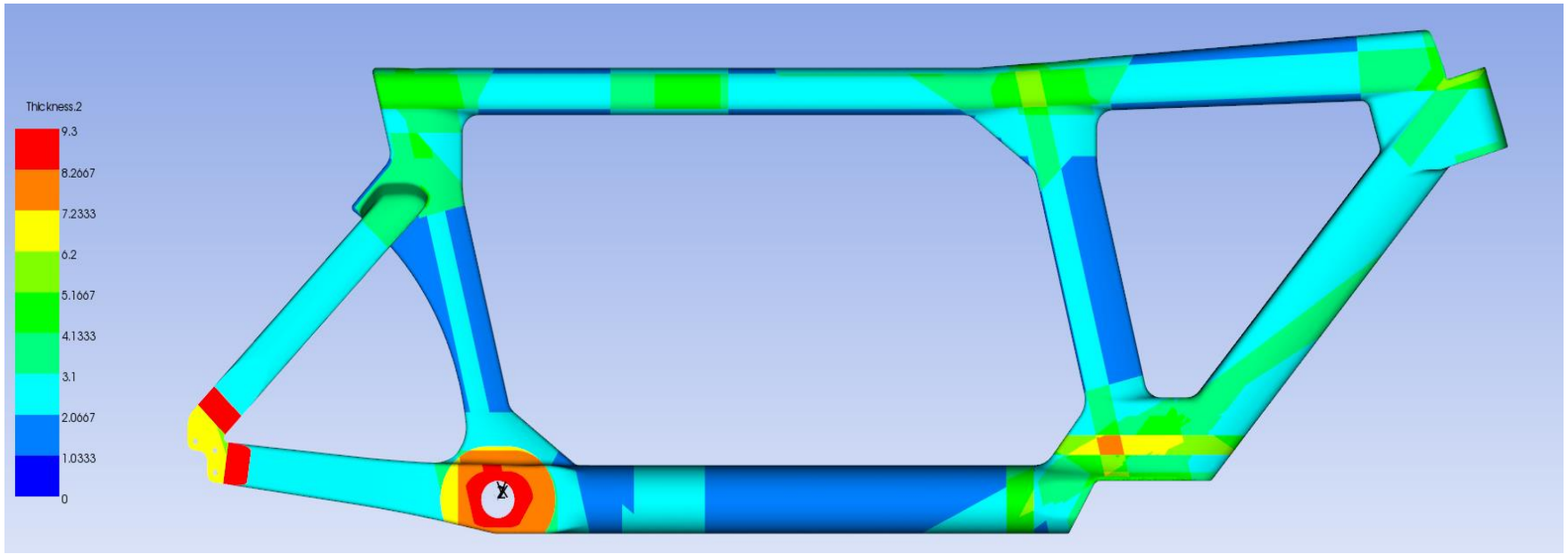


Method: Laminate optimisation

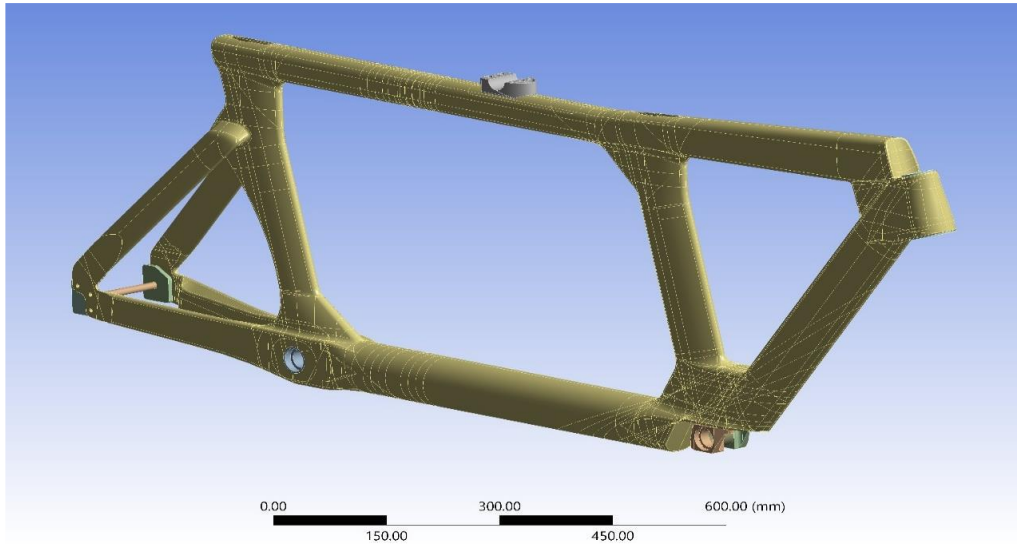
Model of full carbon fibre ply lay-up

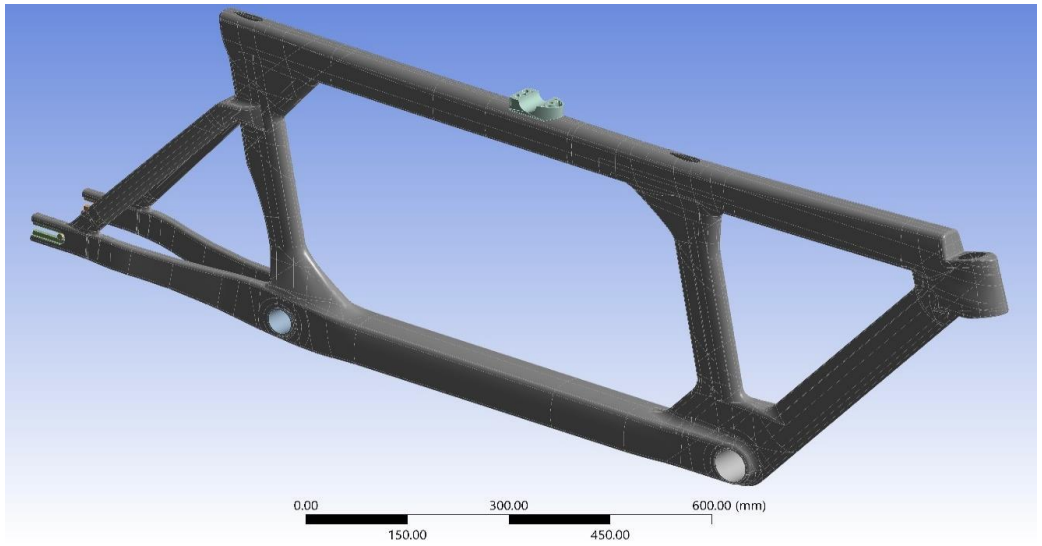


Laminate thickness



Results: 2016 and 2020 frame comparison

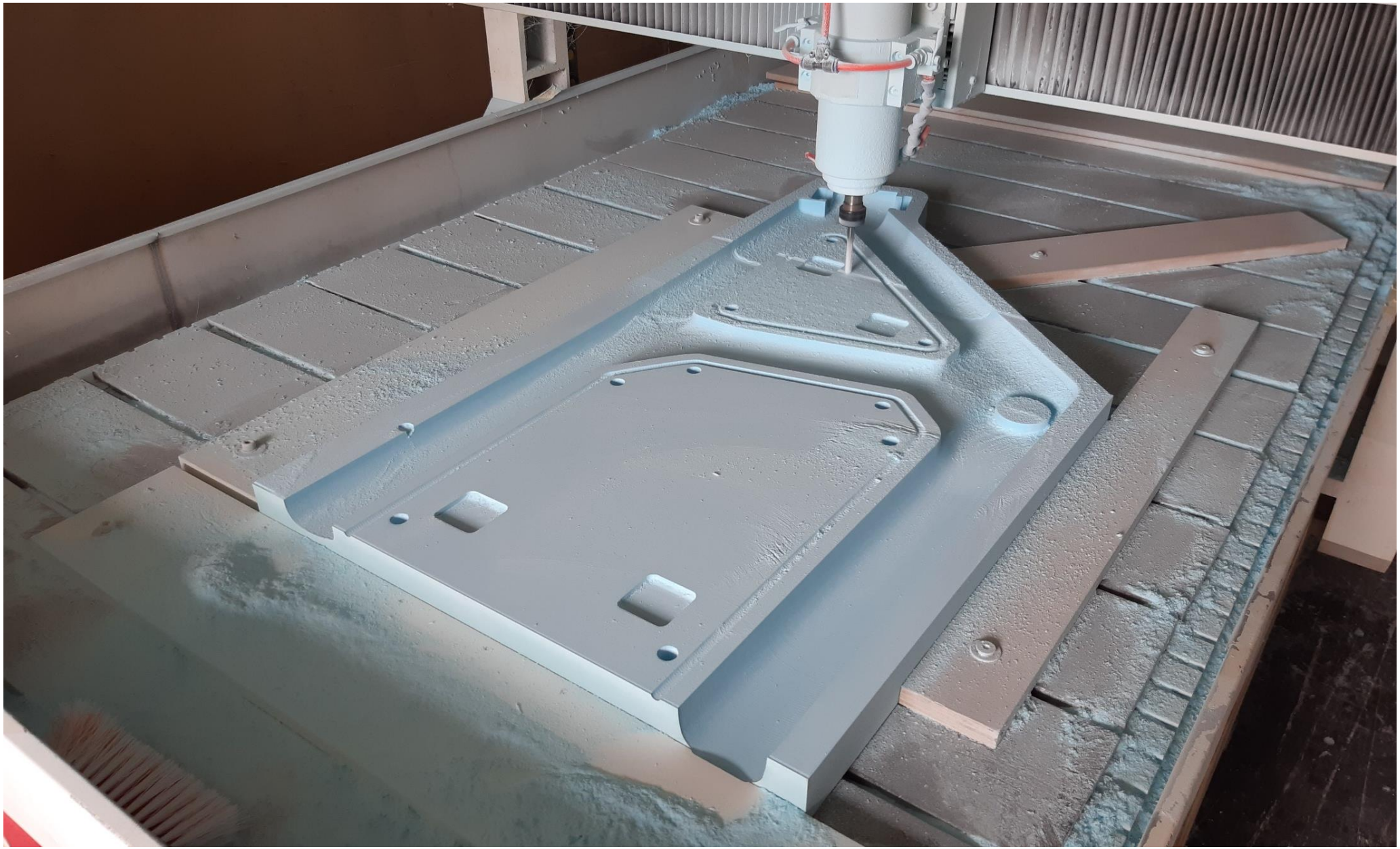




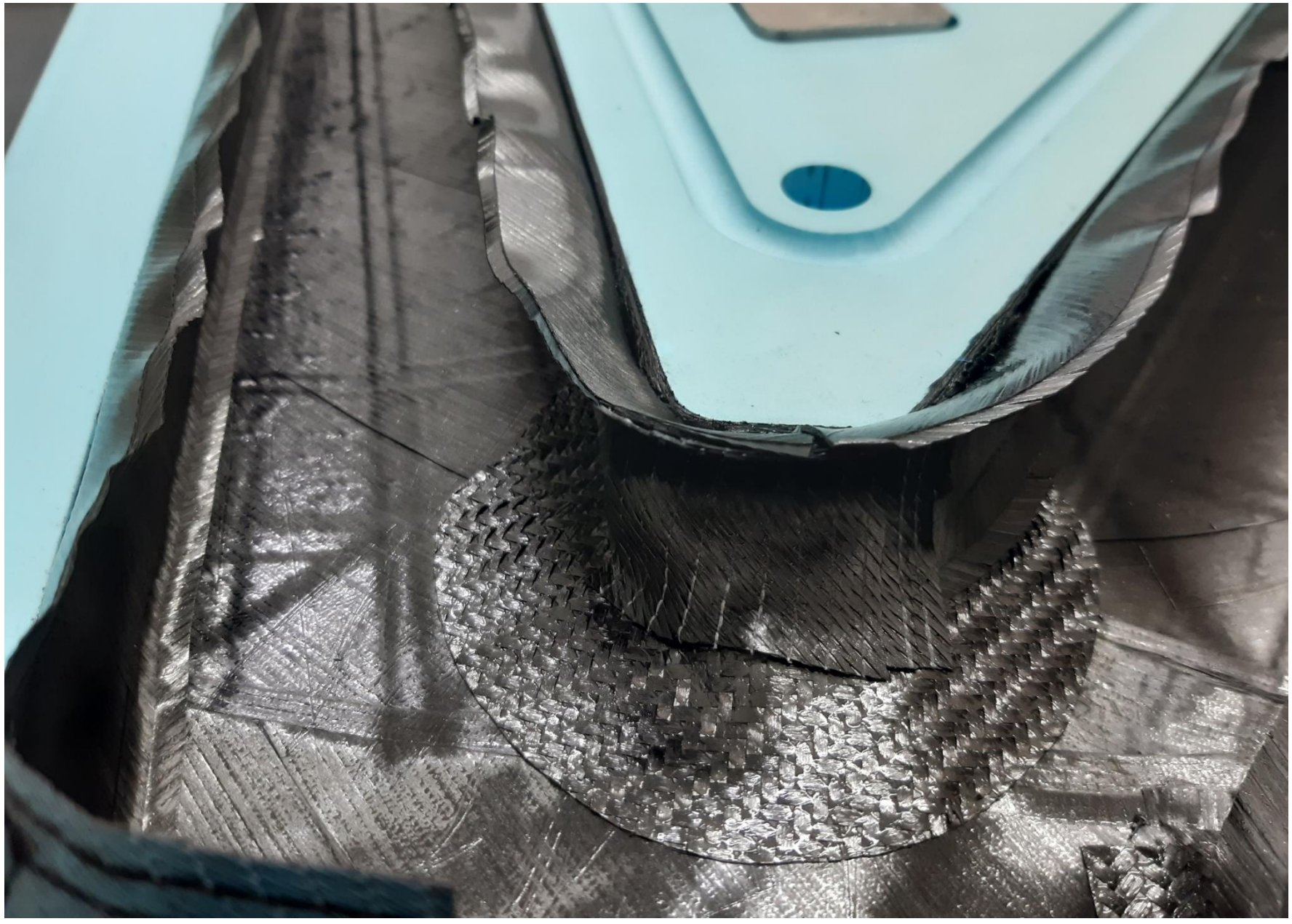
Frame	Rio 2016	Tokyo 2020
Head tube roll	0.52°	0.75° (70% stiffness)
Mass	4.1 kg	3.0 kg (26% lighter)

Effect on performance: 1.5 kg weight saving is worth ~ 0.15s in a 3000m tandem pursuit race

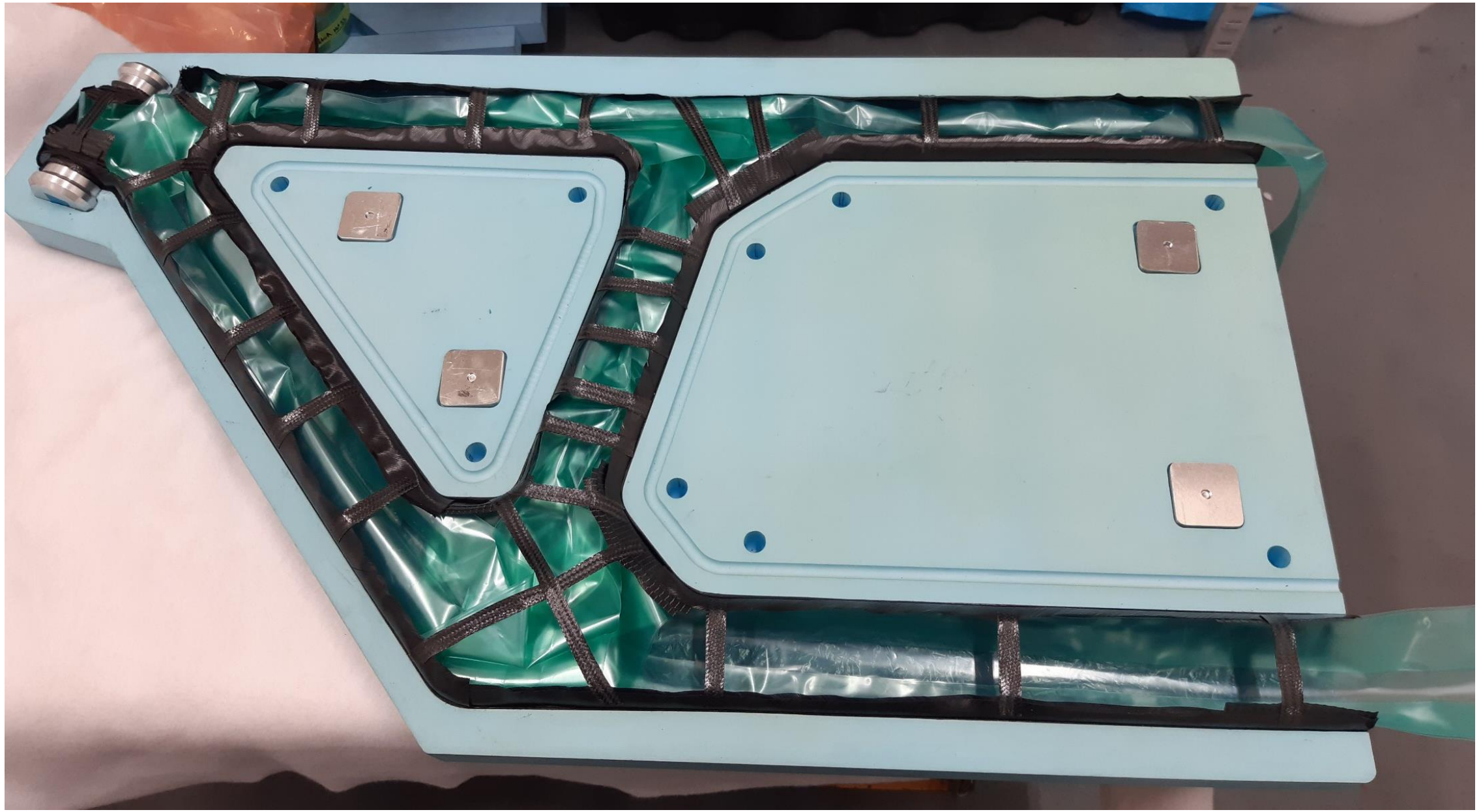
Manufacture: 2020 frame



Manufacture: 2020 frame



Manufacture: 2020 frame



Manufacture: 2020 frame

Manufacture: 2020 frame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New Zealand
MAVIC

Spare slides

Manufacture: 2020 frame

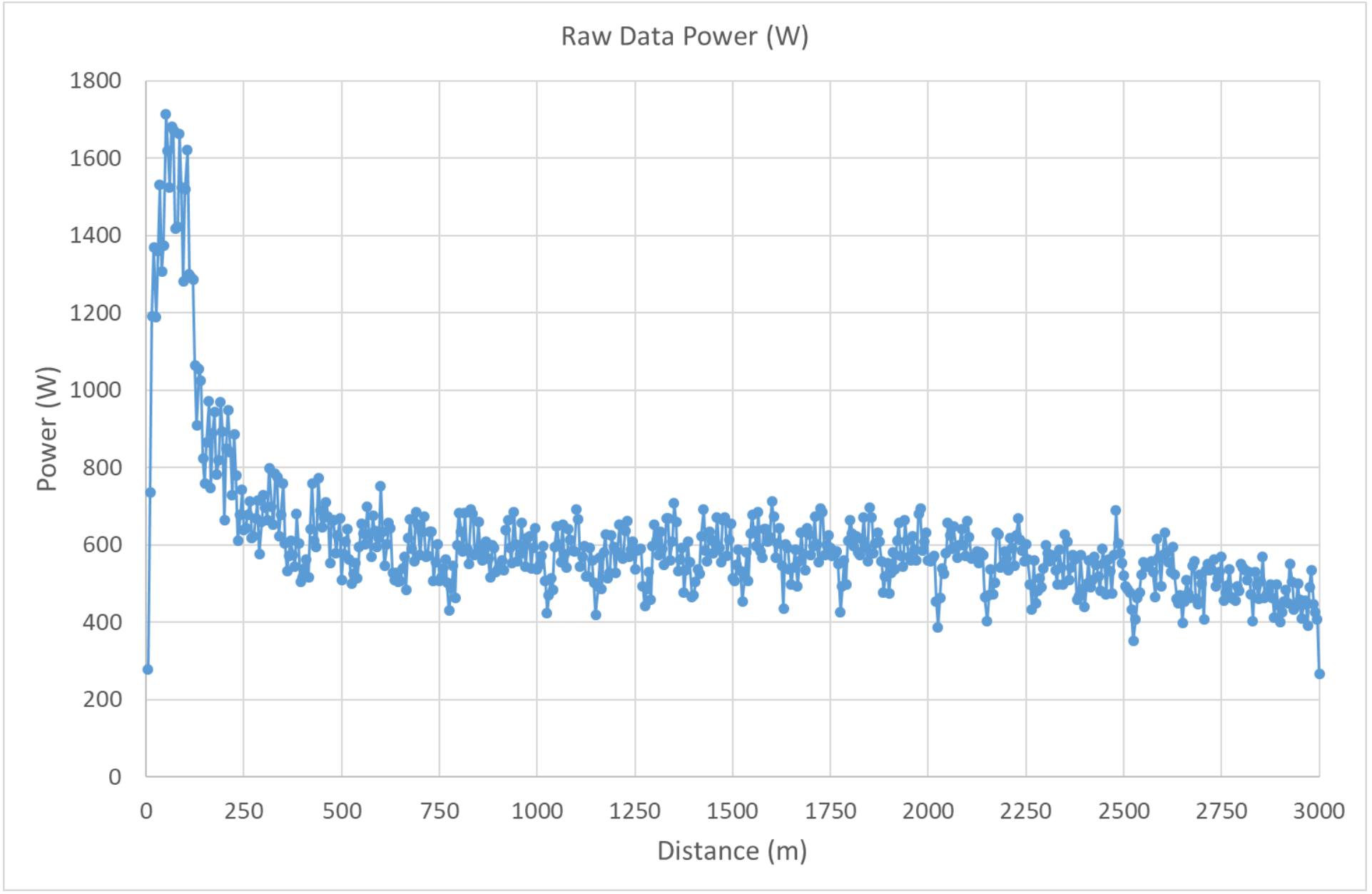
Moulds:
- High temperature epoxy tooling board

Carbon fibre:
- Hankuk brand, high modulus unidirectional and standard modulus woven cloth prepreg.
- Minimum cure temperature of 80 deg C
- Regularly debulked with vacuum during lamination.

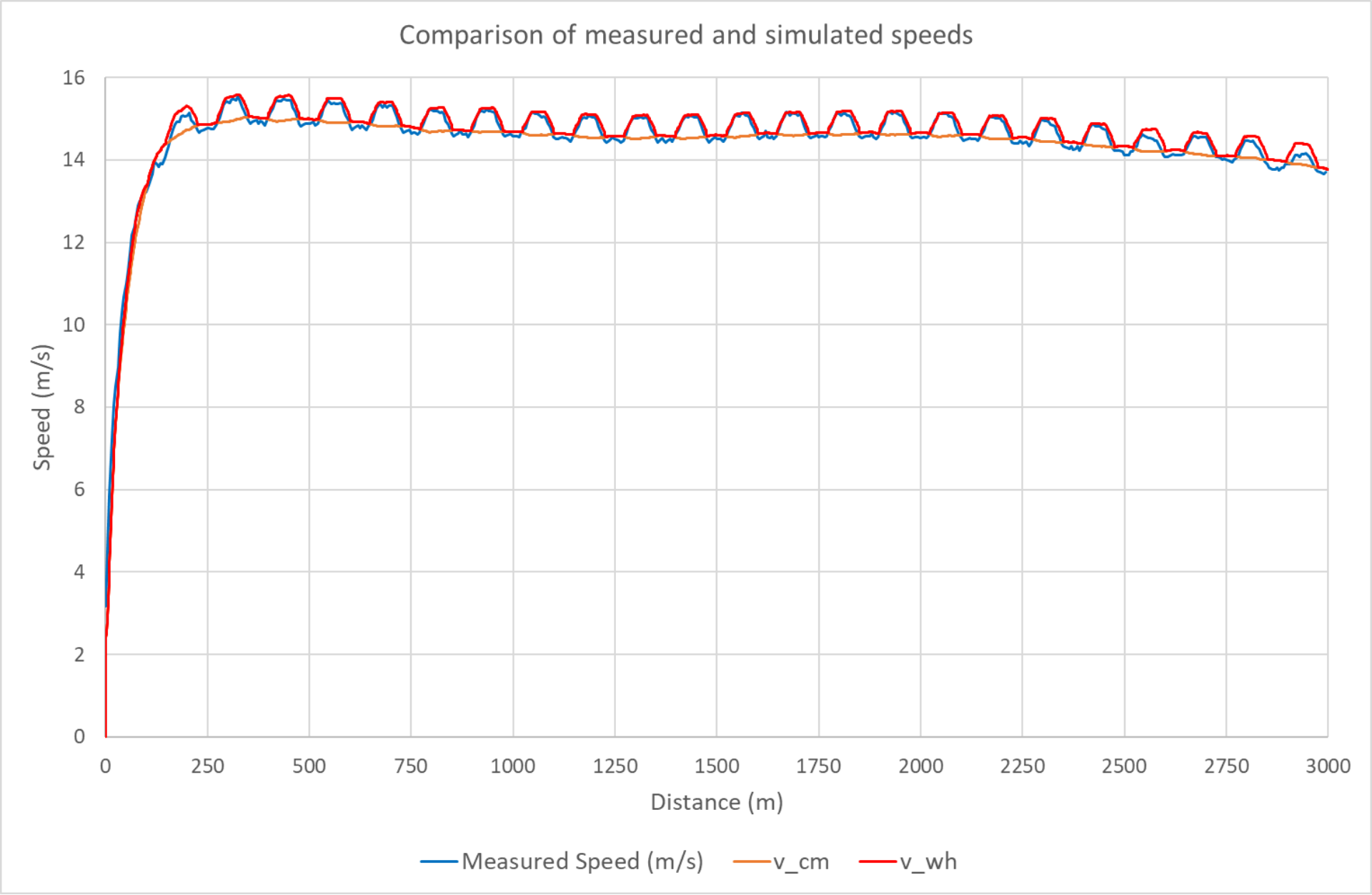
Curing:
- Autoclave with at 110 deg C
- Vacuum and 3.7 bar autoclave pressure

Assembly:
- 4 separate parts (forward frame, aft frame, & 2 seat tube inserts)
- Bonded with HPR rubber toughened room temperature cure epoxy

Numerical modelling of standing start race: Input power profile



Numerical modelling of standing start race: Validation



Numerical modelling of standing start races: Effect of weight saving

- **Female riders: 55 + 65 kg**

- **3000m tandem individual pursuit**
  - **starting torque:** **500 Nm**
  - **average power:** **609 W**
  - **aerodynamic drag area C_dA:** **0.2902 m^2 (0.3352 m^2 for first lap)**

- **Validation**
  - **Simulated finish time:** **208.98s**
  - **Actual finish time:** **208.90s**

- **Effect of total tandem mass**

- **Simulated finish times:**

  - **15 kg tandem:** **209.13s +0.15s**
  - **13.5 kg tandem:** **208.98s**
  - **12 kg tandem:** **208.33s -0.15s**

Motivation: 8 out of 50 Paralympic cycling medals contested on tandems

Paralympic cycling classes:

- C 1-5: Cyclists with an impairment capable of using a standard bicycle
- T 1-2: Cyclists with balance impairment use a tricycle
- H 1-4: Cyclists with leg impairment use a handcycle
- **B: Blind and visually impaired cyclists use a Tandem bicycle with a sighted pilot on the front - both athletes are awarded medals**

Neil Fachie and Matthew Rotherham (GBR)
©SWpix

Motivation: Tandem frame design is a challenge

Conflicting design needs:

- Low mass, good aerodynamics
- High stiffness and strength

Structurally worse than solo bicycle:

- Much higher loading
- Longer wheelbase

Medals for para-sport events in the Commonwealth Games, such as para-cycling tandem sprint, count towards national medal tallies. Tim Ireland/PA

Motivation: Not a new problem

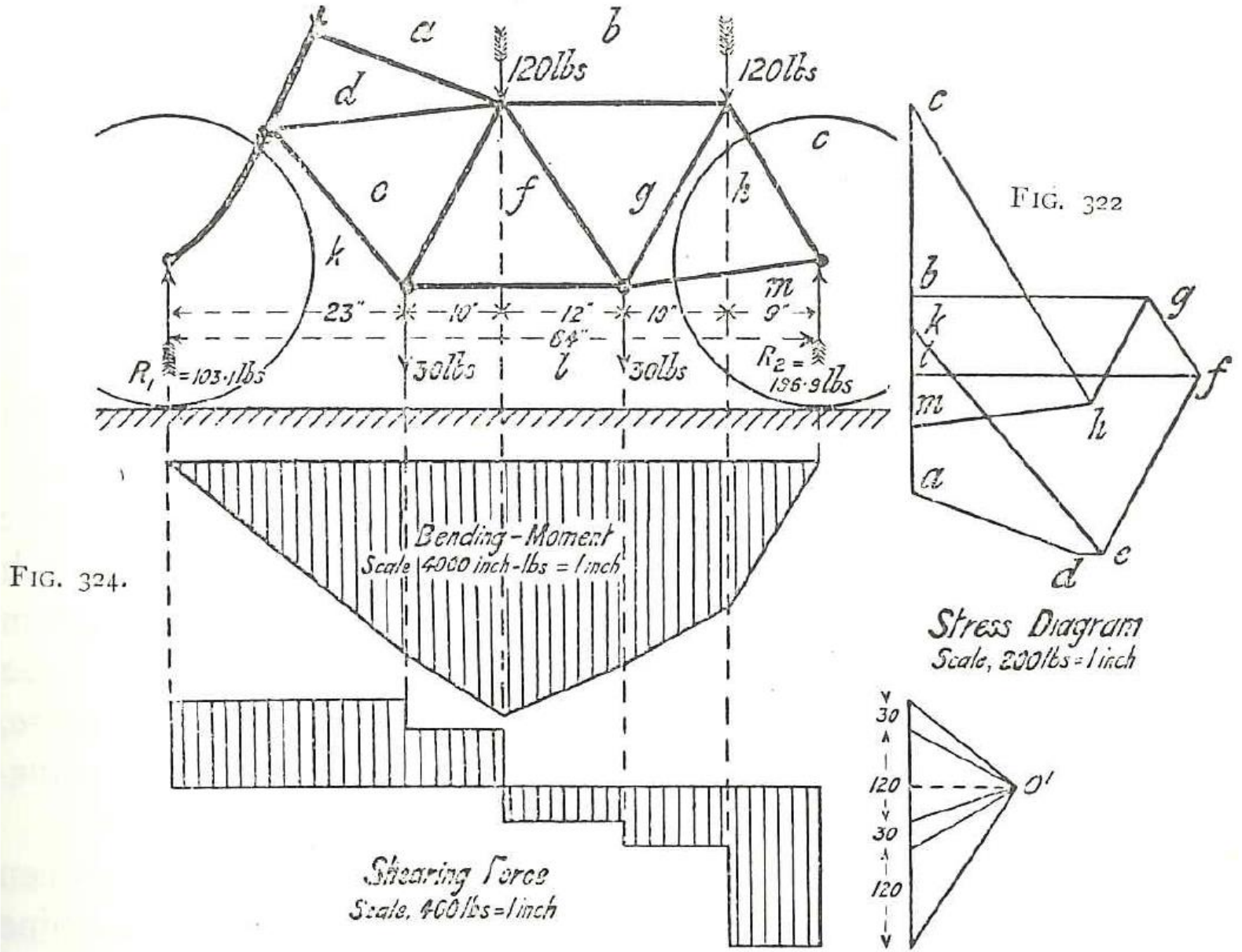


FIG. 324.

FIG. 322

Stress Diagram
Scale, 200lbs = 1 inch

Sharp, A. (1896)

Bicycles and Tricycles: An Elementary Treatise on Their Design and Construction.

Longmans, Green, UK.

Method: Calculation of forces

Approach

- Define bicycle geometry
- Define athlete mass and starting torque
- Consider equilibrium of:
  - Whole bicycle
  - Captain and stoker
  - Rear wheel
  - Both cranksets (pedal & chain forces)
- Output: forces acting on
  - Handlebars
  - Bottom brackets

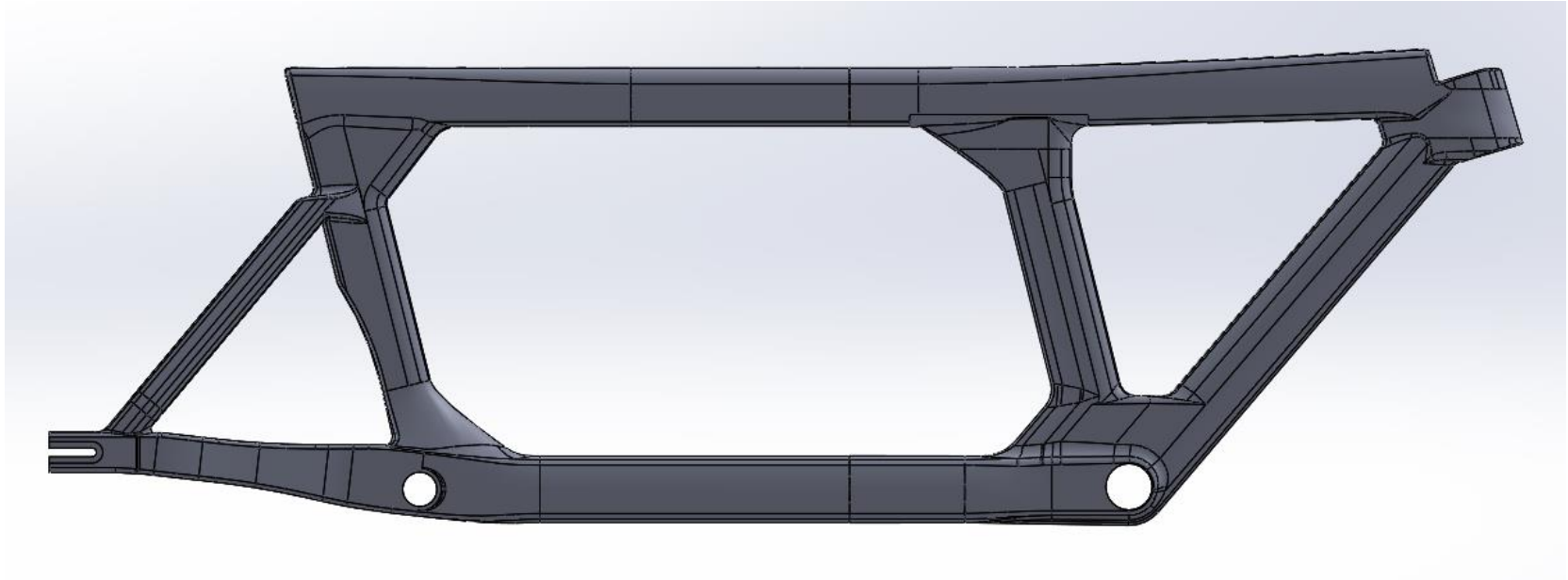
Key assumption

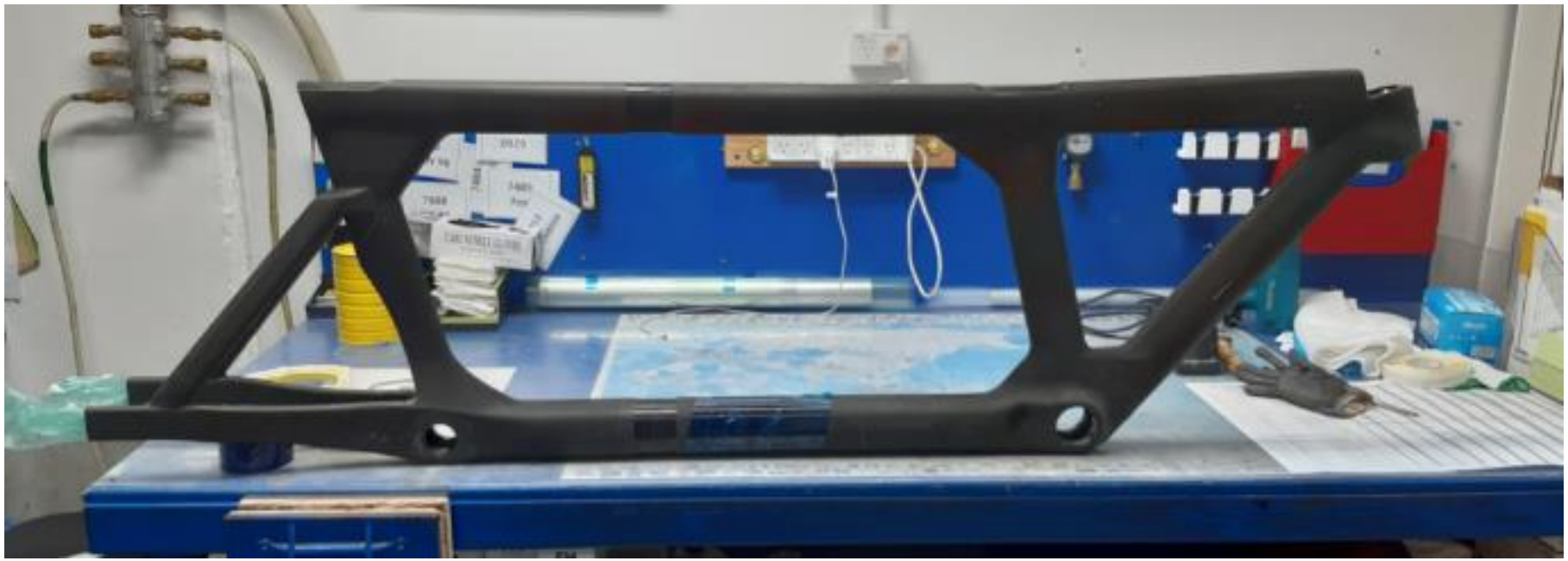
No horizontal forces on pedals

Cyclists

Elite level females: 60 kg & 55 kg, 250 Nm each

Soden, P.D. and Adeyefa, B.A. (1979) Forces applied to a bicycle during normal cycling. *J. Biomechanics* 12:527-541





Motivation: Despite UCI rules, no single design universally adopted to date

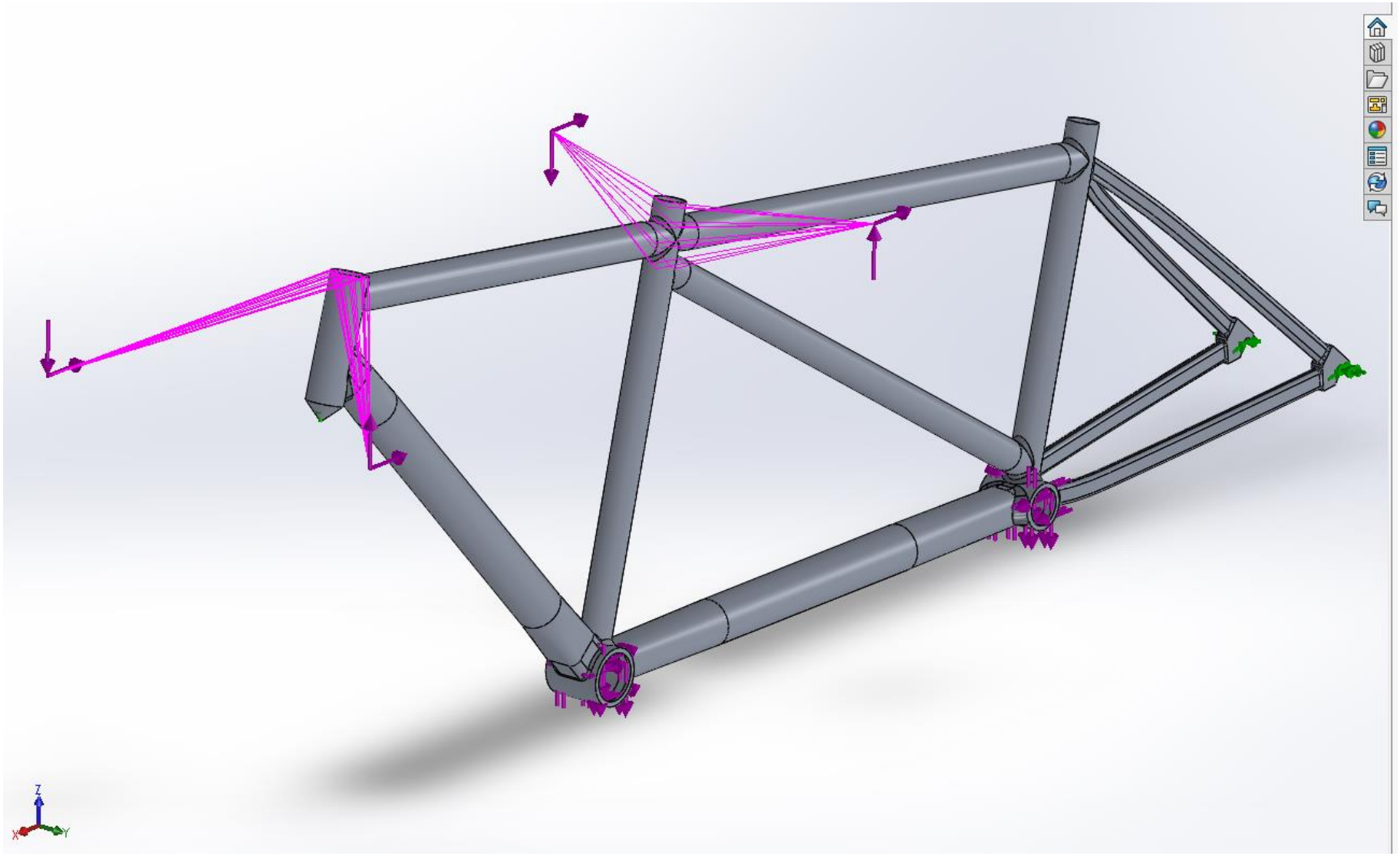
Double diamond

Direct lateral

Marathon

Open frame

Method: Computational structural analysis

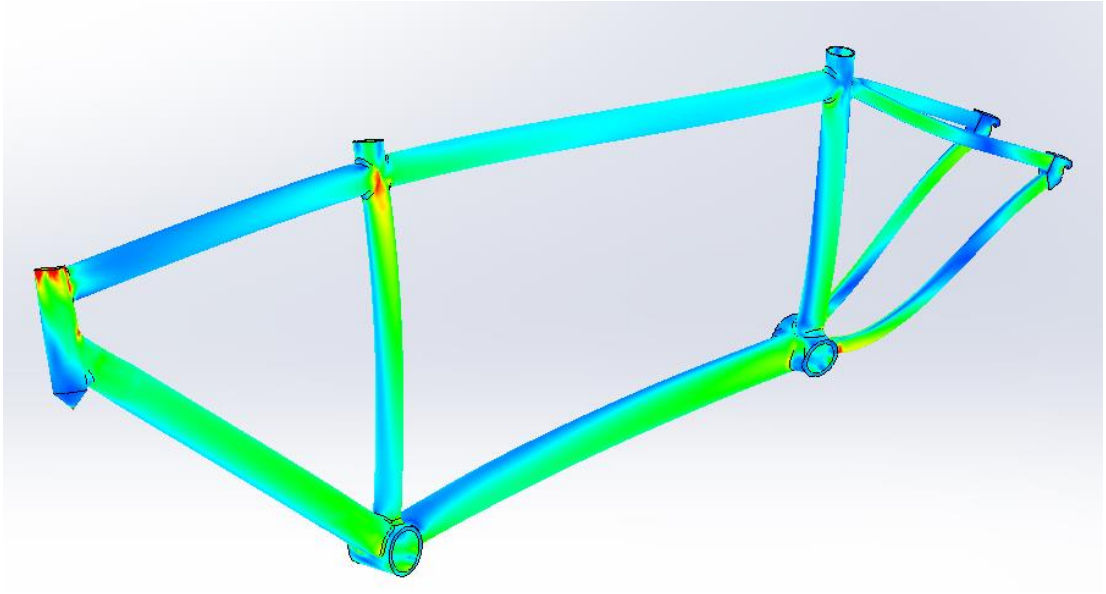


Results: Comparison of two frame types

Open frame

Aluminium tubing
- Diameters: 51 to 35 mm
- Wall thickness: 2 mm

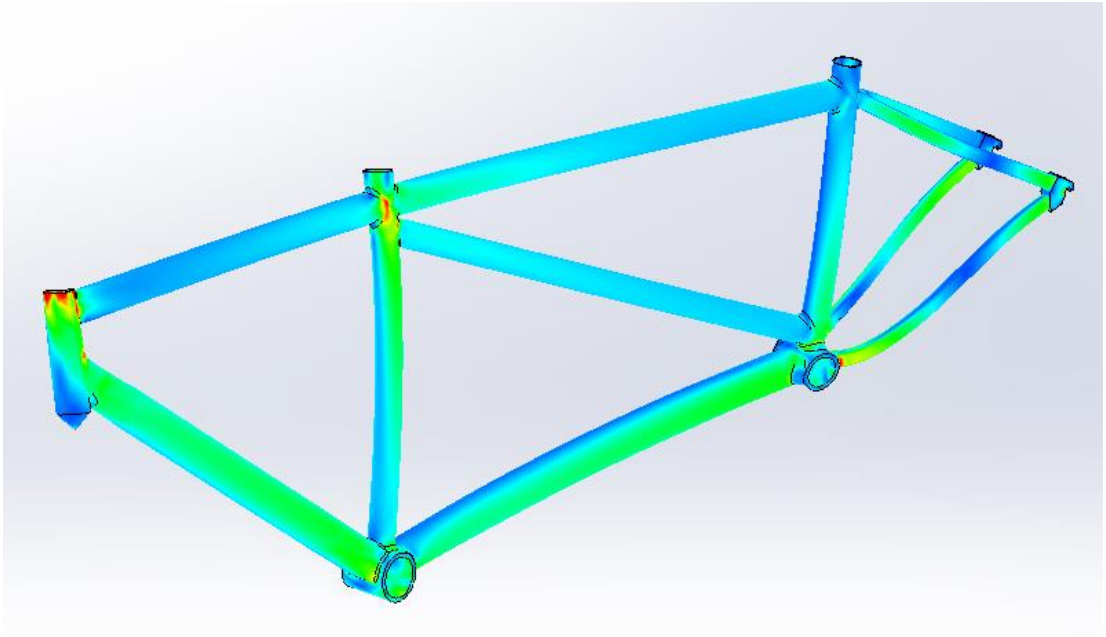
Frame mass: 3.29 kg



Double diamond

3.68 kg (12% heavier)

Vertical deflection
– 297% stiffer
Captain twist
– 8% stiffer
Stoker twist
– 25% stiffer



Conclusions & further work

Stiffness benefits

Additional bracing can provide torsional stiffness improvement. But …..

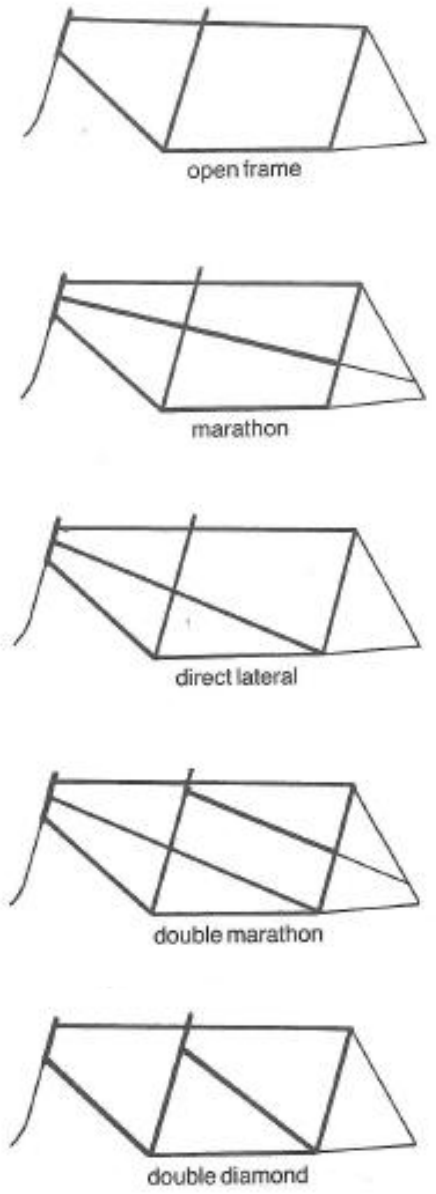
Effect on performance

Weight saving is worth ~ 0.1s/kg over a 3000m tandem pursuit race

Aerodynamic benefits of reduced bracing?

Next steps

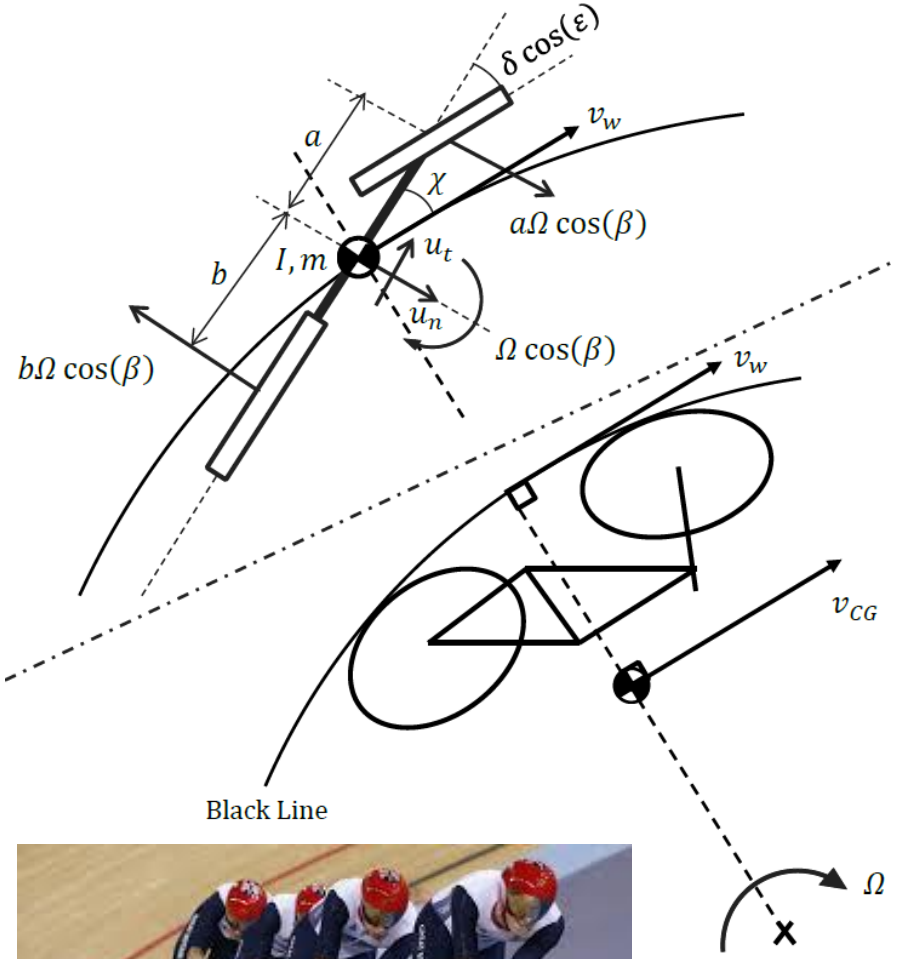
Analyse marathon, double marathon and direct lateral designs



[4] Oliver, T. (1990) Touring bikes: A practical guide, The Crowood Press, UK.

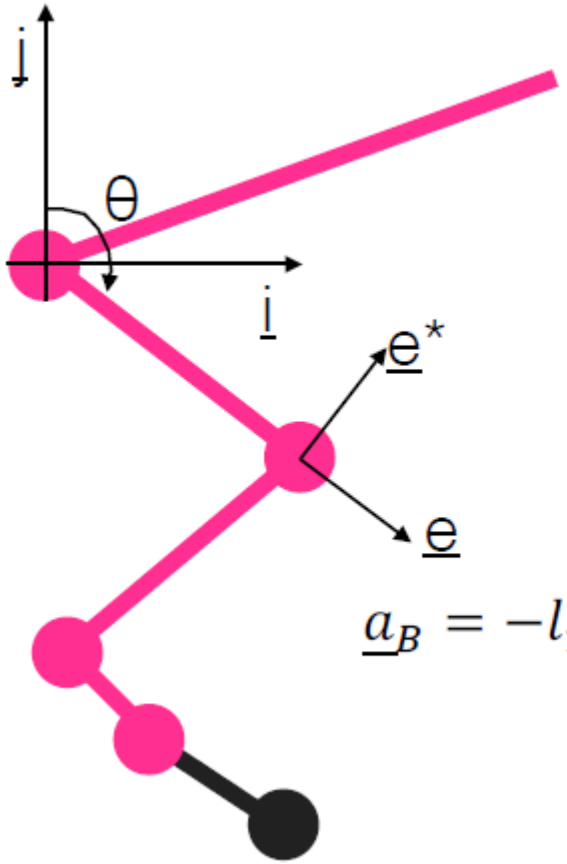
[4]

Sports engineering: Design of optimal strategies for track racing



Kinematic model

Velocity and acceleration of knee



$$\underline{v}_B = l_1\dot{\theta}\sin\theta\,\underline{i} + l_1\dot{\theta}\cos\theta\,\underline{j}$$

$$\underline{a}_B = -l_1\left(\ddot{\theta}\cos\theta + \dot{\theta}^2\sin\theta\right)\underline{i} + l_1\left(\ddot{\theta}\sin\theta - \dot{\theta}^2\cos\theta\right)\underline{j}$$

ENGLISH INSTITUTE OF SPORT

BRITISH CYCLING